# The runoff characteristics and harmonic analysis of the soil moisture dynamics in *Robinia pseudoacacia* stand

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**Abstract:** *Robinia pseudoacacia* stands act as a typical ecological protection forest in hilly semi-arid area of China. Two fields of surface runoff were separately set up in *R. pseudoacacia* stand and its clearcut area in the western Liaoning Province (18°50'-122°25' E, 40°24'-42°34' N) for measuring the characteristics of runoff and sediment as well as soil moisture dynamics. Contractive analysis of the two land types showed that there existed a significant difference in volumes of runoff and sediment between the sites of *R. pseudoacacia* stand and its clearcut area. The runoff volume and sediment volume in clearcut area were much bigger than those in *R. pseudoacacia* stand, with an increase amount of 40%-177% for runoff and 180%-400% for sediment. Hydrograph of surface runoff of typical rainfall showed that the peak value of runoff in *R. pseudoacacia* stand was decreased by 1.0-2.5×$10^{-3}$$m^3 \cdot s^{-1}$ compared with that in its clearcut area, and the occurring time of peak value of runoff in *R. pseudoacacia* stand was 10-20 min later than that in its clearcut area. Harmonic analysis of soil moisture dynamics indicated that the soil moisture in *R. pseudoacacia* stand was 2.3 % higher than that in clearcut area, and the soil moisture both in *R. pseudoacacia* stand and its clearcut area could be divided into dry season and humid season and varied periodically with annual rainfall precipitation. It was concluded that *R. pseudoacacia* stand plays a very important role in storing water, increasing soil moisture, and reducing surface runoff and soil erosion.

**Key words:** Hilly semi-arid area; *Robinia pseudoacacia* stand; Runoff generation characteristics; Soil moisture dynamics; Harmonic analysis

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## Introduction

*Robinia pseudoacacia* is an important tree species to improving ecological environment, controlling soil erosion, adjusting river water table, and providing the fuel in Chinese "three-North" area (Wang 2002). Many researches have been carried out on hydrographic and ecological benefit of *R. pseudoacacia* stand in Loess Plateau (Wang 1994; Zheng 1995; Wang 1991), and most of the researches focused on improving soil physical properties, increasing soil infiltration, decreasing surface runoff and soil loss, etc.. However, few researches were carried out on the water storage, water and soil conservation, and soil moisture dynamics in the artificial protection forest of *R. pseudoacacia* in hilly semi-arid area in China.

The hilly semi-arid area is one of the important land types of the arid area in northern China, with an area about 1.1×$10^5$ $km^2$. It is not only one of the key production bases of foodstuff, fruit and stock farming, but also the northern doorway and ecological wall of North China and its south region (Liu 2000). In this region, there are many artificial protection forests of *R. pseudoacacia,* with the total area of 1.4×$10^4$ $km^2$. Therefore it is necessary to study quantitatively the characteristics of runoff and sediment, soil moisture dynamics in *R. pseudoacacia* stand, and its clearcut area through a fixed observation. The aims of this study is to provide scientific data for regeneration, pattern arrangement, and comprehensive benefits assessment of artificial protection forest of *R. pseudoacacia,* and enrich and improve quantitative assessment theory about hydrographic and ecological benefit of protection forest in "three-North" region (Wang 1998).

## Study area

The experiment was conducted at a typical hilly semi-arid area in the western Liaoning Province (18°50'-122°25' E, 40°24'-42°34' N). The experimental area has semi-arid seasonal climate, with annual mean precipitation of 450-580 mm, annual mean evaporation of 2 088.5 mm, and annual mean temperature of about 8.5°C. The frost-free period is 142 days (Yan 1988). Vegetation of this area belongs to north China flora, and dominant species are *R. pseudoacacia, Pinus tabulae, Platycladus orientalis, Populus davidiana, Caragana microphylla, Lespedeza biaolorcz* and *Zizyphus jujubamill,* and so on. The zonal soil type is Cinnamon Soil, and Eluvial Soil or Forest Cinnamon

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Soil can be seen in remote mountains. Soil pH value is in range of 5.9-8.5.

## Experimental and measuring method

### Surface runoff fields

Two fields of surface runoff were separately set up in *R. pseudoacacia* stand and its clearcut area. The natural conditions of the two fields were similar except vegetation coverage (Table1). Intercepting ditch and triangular measuring weir were built at one end of the two fields. The designed discharge of the triangular measuring weir was 0.212 $m^3 \cdot s^{-1}$.

**Table1. Natural conditions of the surface runoff fields**

| Land type | Area /hm$^2$ | Slope | Direction | Soil thickness /cm | Matrixes | Vegetations |
|---|---|---|---|---|---|---|
| *Robinia. pseudoacacia* stand | 1.00 | 25°-30° | East | Cinnamon 40-50 | Calcareousness | 8-10 years old R. pseudoacacia, with coverage of 80%~90%. Shrub and herbage include Caragana microphylla and Setaria lutescens, with a coverage of 15% |
| Clearcut area | 1.04 | 20°-28° | East | Cinnamon 30-40 | Calcareousness | Clearcut was made 2 years ago. Shrub and herbage include Setaria lutescen, and Artemisia sp., with a coverage of 30% |

### Runoff and sediment

The runoff volume was measured by sediment pool, automatic water-stage recorder, and triangular measuring weir. Sediment volume was the sum of dry weights of suspended load and tractional load, while dry weight of suspended load was the weight of sand being filtrated from the runoff sample, and that of tractional load was the weight of sand depositing in sediment pool (Khai 1997).

### Soil moisture

The soil moisture contents of 0-10 cm, 10-20 cm and 20-30 cm layer were separately measured by using the oven dry method at the spots on upper, middle and down slopes on 1st, 11th and 21st day of each month. At the same time, the dynamic laws of soil moisture were analyzed by the harmonic analysis method. The basic principle of harmonic analysis method is to use the known periodic function (or time series) and Fourier series method to gain the discontinuous spectrum, and then to calculate the harmonic factor of key period. According to Fourier theorem, under certain conditions, the arbitrary function [*f(t)*] can be expressed by the sum of arbitrary sine (or cosine) trigonometric function.

$$f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} C_k \cdot \sin(k \cdot w \cdot t + \theta_{k,0})$$

$$= \frac{a_0}{2} + \sum_{k=1}^{\infty} C_k \cdot \cos(k \cdot w \cdot t + \theta_{k,0})$$

$$= \frac{a_0}{2} + \sum_{k=1}^{\infty} [a_k \cos(k \cdot \omega \cdot t) + b_k \sin(k \cdot \omega \cdot t)]$$

where, $a_k$, $b_k$ is Fourier coefficient, *k* is wave numbers of harmonic component (*k*=0, 1, 2...), $C_k$ is amplitude of the "k" wave; $\theta_{k,0}$ is first phase of the "k" wave, $\omega = 2\pi/t$ is basic frequency, *t* is basic period, t/k is period of the "k" wave; *f(t)* is the arbitrary function; $a_0$ is Fourier coefficient when k is zero.

Meanwhile, with the random probability decision method of A•Schuster, the significant test of the harmonic period was carried out. When the periodic amplitude $C^2 - C_\alpha^2 \geq 0$, it was significant, and otherwise it was not significant (Huang 1983; Guan 1989).

## Results and analysis

### Contrastive analysis of runoff and sediment

There existed a significant difference in volumes of runoff and sediment between the sites of *R. pseudoacacia* stand and its clearcut area. The runoff volume and sediment volume in clearcut area were much bigger than those in *R. pseudoacacia* stand (Table 2), with an increase amount of 40%-177% for runoff and 180%-400% for sediment. This indicated that *R. pseudoacacia* stand could reduce surface runoff and oil erosion and increase infiltration of rainfall (Yu 1991).

**Table2. Runoff volume and sediment volume in *R. pseudoacacia* stand and its clearcut area**

| Number | Amount of rainfall /mm | Intensity of rainfall intensity /mm·min$^{-1}$ | Runoff volume /mm: Wood land | Runoff volume /mm: Clearcut area | Runoff volume /mm: Amount of increase /% | Sediment volume /t·km$^{-2}$: Wood land | Sediment volume /t·km$^{-2}$: Clearcut area | Sediment volume /t·km$^{-2}$: Amount of increase /% |
|---|---|---|---|---|---|---|---|---|
| $N_{01}$ | 54.1 | 0.55 | 7.033 | 13.918 | 97.9 | 30.01 | 150.08 | 400.1 |
| $N_{02}$ | 30.5 | 0.22 | 3.051 | 4.491 | 47.2 | 27.95 | 78.34 | 180.3 |
| $N_{03}$ | 32.4 | 1.10 | 4.212 | 10.972 | 160.5 | 14.34 | 63.58 | 343.4 |
| $N_{04}$ | 17.8 | 0.21 | 1.780 | 3.115 | 75.0 | 12.90 | 38.57 | 199.0 |
| $N_{05}$ | 42.4 | 0.77 | 5.310 | 12.930 | 143.5 | 20.00 | 100.00 | 400.0 |
| $N_{06}$ | 38.2 | 0.84 | 4.966 | 13.756 | 177.0 | 21.95 | 105.25 | 379.5 |

**Reason and hydrologic process of runoff occurrence**

Based on the runoff characteristics in hilly semi-arid area, the following hydrologic equation was used to express runoff volume,

$$R_s(t) = \int_0^t i \cdot dt - \int_0^t i_n \cdot dt - \int_0^t e \cdot dt - \int_0^t s_d \cdot dt - \int_0^t f \cdot dt \qquad (1)$$

where, $R_s(t)$ is amount of runoff on sloping land, $i$ is rainfall intensity, $i_n$ is rainfall interception rate, $e$ is evaporation rate, $S_d$ is filling lowland rate, $f$ is soil infiltration rate.

During a rainfall, $i_n$, $e$ and $S_d$ can be ignored because they are small and do not cause runoff directly. Thus, the amount of runoff depends on the first item ($i$) and last item ($f$) of equation (1). By calculating equation (1) we can obtain Equation (2):

$$dR\ (t)\ /\ dt\ =\ \alpha\ =\ i\ -\ f \qquad (2)$$

From equation (2), we can find the runoff rate of woodland mainly depends upon $i$ and $f$. Under natural rainfall condition, runoff occurs when $i > f$, but no runoff occurs when $i \leqslant f$.

Therefore, through hydrograph of surface runoff of typical rainfall (Figs.1, 2), we could find that the peak value of runoff in *R. pseudoacacia* stand was decreased by 1.0-2.5×10$^{-3}$m$^3$·s$^{-1}$ compared with that in its clearcut area. This demonstrated that *R. pseudoacacia* stand could decrease the peak value and volume of runoff. Meanwhile, the occurring time of peak value of runoff in *R. pseudoacacia* stand was 10-20 min later than that in its clearcut area, which indicated that *R. pseudoacacia* stand could store water and delay the occurring time of flood peak.

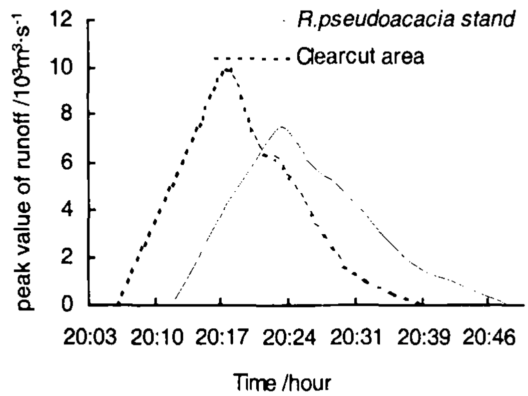


**Fig. 1 Hydrograph of surface runoff of the $N_{01}$ typical rainfall**

**Harmonic analysis of soil moisture dynamics**

*Zero wave value* ($\theta_0$ *-the mean soil moisture content)*

The zero wave values of harmonic analysis of soil moisture dynamics ($\theta_0$) in *R. pseudoacacia* stand and its clearcut area were significantly different (the variance analysis results: $F$=7.823 > $F_{0.01}$=7.560). The soil moisture in *R. pseudoacacia* stand was higher than that in clearcut area with an increase amount of 2.3% (Table 3), especially in the rainy season, it was 2.40%-3.66% higher than that in clearcut area. The results demonstrated that *R. pseudoacacia* stand could intercept and reallocate rainfall runoff and increase soil moisture.

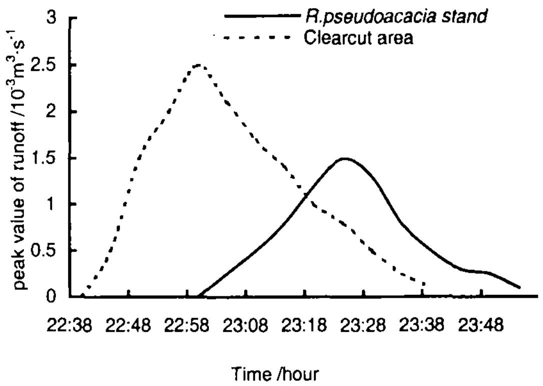


**Fig. 2 Hydrograph of surface runoff of the $N_{02}$ typical rainfall**

*Periodic test of harmonic analysis of soil moisture dynamics*

The periodic test $S$ value of harmonic analysis of soil moisture dynamics showed that the first waves of soil moisture in *R. pseudoacacia* stand and its clearcut area were significant ($\alpha$=0.1), and the second and third waves were not significant (Table 4). In harmonic analysis, the first wave, the second wave, and third wave are separately called the year wave, half a year wave and seasonal wave, and they form the key period of time series variation. Hence, the results of harmonic analysis also indicated that the soil moisture both in *R. pseudoacacia* stand and its clearcut area could be divided into dry season and humid season and varied periodically with annual rainfall precipitation, i.e., the soil moisture was lower between the end of April to the end of June, began to increase from the early of July to mid-September, and decline from the end of September.

## Conclusions and suggestions

The results of this study showed that *pseudoacacia* stand. The runoff volume and sediment volume in clearcut area were much bigger than those in *R. pseudoacacia* stand (Table 2), with an increase amount of 40%-177% for runoff and 180%-400% for sediment These indicated that *R. pseudoacacia* stand could decrease surface runoff and soil erosion, and increase infiltration of rainfall.

Through hydrograph of surface runoff of typical rainfall, we found that *R. pseudoacacia* stand could decrease the peak value and the runoff volume, store water and delay the occurring time of flood peak.

By the harmonic analysis of soil moisture dynamics, we found the soil moisture in *R. pseudoacacia* stand and its

clearcut area were both divided into dry season and humid season and varied periodically with annual rainfall precipitation. The soil moisture was higher between the early of July to mid-September, and then began to decline from the end of September. The soil moisture was lower from the end of April to the end of June. The annual mean soil moisture in *R. pseudoacacia* stand was higher than that in its clearcut area, in the rainy season, more than 2.40%-3.66%. So the results indicated that *R. pseudoacacia* stand could intercept and reallocate rainfall runoff, and increase soil moisture.

**Table 3. The zero wave values of harmonic analysis of soil moisture dynamics ($\theta_0$)**

| Land type | Locality | Soil moisture dynamics ($\theta_0$) | | | |
|---|---|---|---|---|---|
| | | Different soil layer /cm | | | Average |
| | | 0-10 | 10-20 | 20-30 | |
| *R. psudoacacia* stand | Slope base | 11.6 | 10.3 | 9.7 | 10.5 |
| | Mid slope | 11.9 | 10.6 | 10.4 | 10.9 |
| | Crest slope | 12.5 | 11.8 | 11.3 | 12.1 |
| Average | | 12.0 | 10.9 | 10.5 | 11.3 |
| Clearcut area | Slope base | 9.2 | 8.9 | 8.4 | 8.8 |
| | Mid slope | 9.2 | 8.6 | 8.4 | 8.8 |
| | Crest slope | 9.8 | 9.3 | 9.4 | 9.5 |
| Average | | 9.4 | 8.9 | 8.7 | 9.0 |

**Table 4. The periodic test $S'$ value of harmonic analysis of soil moisture dynamics**

| Land type | Locality | *S* value of different locality | | | *S* value of different land type | | |
|---|---|---|---|---|---|---|---|
| | | First wave | Second wave | Third wave | First wave | Second wave | Third wave |
| *R. psudoacacia* stand | Slope base | 1.320 | -0.547 | -1.311 | 1.612 | -0.533 | -1.741 |
| | Mid slope | 1.610 | -0.544 | -1.932 | | | |
| | Crest slope | 1.468 | -0.563 | -1.915 | | | |
| Clearcut area | Slope base | 0.378 | -0.313 | -0.454 | 0.642 | -0.518 | -0.760 |
| | Mid slope | 0.614 | -0.481 | -0.857 | | | |
| | Crest slope | 0.467 | -0.504 | -0.758 | | | |

When the periodic amplitude $S = C^2 - C_a^2 \geq 0$, it is significant ($\alpha$=0.1), and otherwise it is not significant.

According to the study, the benefits of soil and water conservation of artificial protection forest of *R. pseudoacacia* were obvious. Therefore, we should speed up the construction of artificial protection forest of *R. pseudoacacia* in hilly semi-arid area in China. Moreover, because of *R. pseudoacacia* being also a key tree for fuel forest, we should pay more attention to its cutting style, cutting cycle, and regeneration after removal of old growth.

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